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Effect of gamma radiation on the lipid profiles of soybean, peanut and sesame seed oils

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RESUMEN

Efecto de la radiación gamma sobre el perfil lipídico de los aceites de semillas de soja, cacahuete y sésamo

Semillas de soja, cacahuete y de sésamo se expusieron a diferentes dosis de radiación gamma (0,0, 0,5, 1,0, 2,0, 3,0, 5,0 y 7,5 kGy). Se determinaron los perfiles de ácidos grasos y el insaponificable de los aceites mediante cromatografía de gases y espectrometría de masas. Los resultados demostraron que las relaciones de ácidos insaturados a ácidos grasos totales saturados (TU/TS) e hidrocarburos totales a esteroles (TH/TSt) se alteró significativamente tras la irradiación. Estos cambios se observaron claramente en el aceite extraído de las semillas de sésamo irradiados, en comparación con los aceites de soja y cacahuetes irradiados. El mayor cambio en la composición de ácidos grasos fue la disminución de la cantidad de ácidos grasos insaturados (C18:1 y C18:2) en todos los casos. En contraste, los niveles de las fracciones de esteroles como colesterol, campesterol, estigmasterol y β-sitosterol de las semillas irradiadas fueron en general más bajo que el de las semillas sin irradiados.

PALABRAS CLAVE: *Ácidos grasos – Esteroles – Hidrocarburos – Irradiación Gamma – Semillas oleaginosas.*

SUMMARY

Effect of gamma radiation on the lipid profiles of soybean, peanut and sesame seed oils

Seeds of soybean, peanut, and sesame were exposed to various doses of gamma irradiation (0.0, 0.5, 1.0, 2.0, 3.0, 5.0 and 7.5 kGy). Fatty acid and unsaponifiable profiles of the extracted oils were separated by gas chromatography mass spectroscopy. The results demonstrated that the ratios of unsaturated to saturated total fatty acids (TU/TS) and total hydrocarbons to sterols (TH/TSt) were significantly altered upon irradiation. These changes were clearly observed in the oil extracted from irradiated sesame seeds compared with the oils from irradiated peanuts and soybean. The major change in fatty acid composition was the decrease in the quantity of unsaturated fatty acids (C18:1 and C18:2) in all cases. In contrast, the sterol fractions such as cholesterol, campesterol, stigmasterol and β-sitosterol levels of irradiated seeds were generally lower than that of the un-irradiated seeds.

KEY-WORDS: Fatty acids – Gamma irradiation – Hydrocarbon – Oil seeds – Sterol.

1. INTRODUCTION

Soybean oil is commonly called “vegetable oil” and considered the world’s largest oilseed crop, with about 13 million tons of oil produced each year (Patterson, 1989). Soybeans are in high demand due to their high protein and oil contents (Erickson *et al.,* 1980). They contain roughly from 19 to 25% oil, of which triglycerides are the major component. Soybean oil is characterized by relatively large amounts of the polyunsaturated fatty acids (PUFA), *i.e.,* ~55% linoleic acid and ~8% α-linolenic acid with few oleic acids of the total fatty acids (Messina, 1997).

Peanuts are of great importance in foods worldwide. Peanut oil contents in 17 cultivars ranged from 45.7 to 51.8% (Nelson *et al.,* 2000). It is a pale yellow, non-drying oil containing large quantities of arachidonic, oleic, linoleic, palmitic and stearic acids. There are also small concentrations of behenic and lignoceric acids, about 1.5% each (Oyinlola *et al.,* 2004). Sesame (*Sesamum indicum* L.) is a very ancient oilseed crop and one of the earliest domesticated oil crops in the world. It acquired importance as a source of cheap vegetable oil and proteins, a good source of natural antioxidants (sesamin and sesamolin) dñp0pwhich are unique for sesame and present in the oil (Ashri, 2007). The total lipid fraction of 28 sesame cultivars ranged from 46.5 to 60.0%. The fatty acid composition in sesame oil consist mainly of linoleic and oleic acids with small amounts of saturated fatty acids. However, the brown seed variety was higher in oleic acid and lower in linoleic, palmitic and stearic acids (Mohamed and Awatif, 1998). In the last decade, γ-irradiation has drawn attention as a new and rapid method for improving the qualitative and quantitative characteristics of many crops. Gamma irradiation has been widely applied in medicine and biology in terms of biological effects induced by a counter intuitive switch-over from low doses stimulation to high-doses inhibition (Charbaji and Nabulsi, 1999, Afify *et al.,* 2012). Irradiation processing is mainly employed to extend the shelf-life and secure the quality of foods by decreasing the microbial load which causes the spoilage of food. It is an appropriate approach for the disinfection of cereals, spices, dried fruits and nuts (El-Beltagi 2001, Cetinkaya *et al.,* 2006). The importance of the irradiation process is not only due to its efficiency for the destruction of undesired microorganisms and extension of shelf-life, but also for its effects

on the physico-chemical, nutritive, and biological characteristics of foods (Dogbevi *et al.,* 1999, Golge and Ova, 2008). Gamma rays are known to influence plant growth and development by inducing cytological, genetic, biochemical, physiological and morphogenetic changes in cells and tissue (Gunckel and Sparrow, 1961). Also, it has been shown to enhance the production of reactive oxygen species (ROS) in a variety of cells resulting from oxidative stress (Repine *et al.,* 1981; von Sonntag, 1987, Xienia *et al.,* 2000). Recent evidence suggests that reactive oxygen species play an important role in the action of ionizing radiation (Ewing and Jones, 1987, Alaoui *et al.,* 1992, Aly and El-Beltagi 2010; Afify *et al.,* 2011a). ROS are the byproducts of many degenerative reactions in crop plants, which will affect the regular metabolism by damaging the cellular components (Foyer and Noctor, 2002). Extensive study on oxidative stress has demonstrated that exposure of plants to adverse environmental conditions induces the overproduction of reactive oxygen species (ROS), such as superoxide radical (O_2^-), H_2O_2 and hydroxyl radical ($HO^\bullet$) in plant cells (Wise and Naylor, 1987, El-Beltagi, 2011). In addition, ROS are highly reactive to membrane lipids, protein and DNA (Afify *et al.,* 2011b, El-Beltagi *et al.,* 2011a,b, El-Beltagi *et al.,* 2012). Irradiation has been shown to cause some physicochemical changes such as reducing viscosity, increasing water solubility, acidity, etc. in starchy foods (Lee *et al.,* 2003, Yook *et al.,* 2004). The low radiation dose used could have produced its long-term effects in part by means of the stimulation of lipid degradation, possibly mediated through the action of free radicals that are known to be generated after irradiation (Katsaras *et al.,* 1986, Voisine *et al.,* 1991). In plant tissues subjected to different forms of stress, lipids are degraded to generate free fatty acids and diacylglycerols, resulting in an eventual accumulation of TG as a defense mechanism (Olsson, 1995). In animal cells, the metabolites of polyunsaturated fatty acids including hydroperoxy fatty acids represent an important class of biological mediators which are released as a result of treatment with ionizing radiations (Steel *et al.,* 1988). It is rather important to determine whether ionizing radiation may be involved in the synthesis of oxygenated polyunsaturated fatty acids in foods of plant origin. Polyunsaturated fatty acids are susceptible to oxidation by radical processes. It is well known that free radicals are formed in food by ionizing radiation (Wills, 1980). The general mechanism of the radiolysis of fats was lead to primary ionization, followed by migration of positive charges towards the carboxyl groups and the double bond cleavage at preferential positions near the carbonyl group. The resulting free radicals engage in various reactions leading to the formation of stable radiolytic products, which have been classified as primary, recombination, and secondary products according to the mode of their formation; but in the case of unsaturated fatty acids, the dimerization reaction appear to be of major importance (Nawar, 1978). The irradiation of lipids with 10 kGy reduced the amount of trienoic fatty acids with triple bonds while double bonds were correspondingly increased; therefore polyenoic acids were the main source of oxidative deterioration problems in fats (Sokolov, 1965). Ionizing radiation caused the oxidation of lipids, even in the absence of oxygen through decarboxylated and unsaturated fatty acids polymerized, but in the presence of oxygen, and hydroperoxides and carbonyls were formed (Lawrie, 1974). Gamma radiation treatments caused a loss of tocopherols in the peanut oil extracted (Bhatti *et al.,* 2010). Since Nawar's group (Champagne and Nawar, 1969; Dubravcic and Nawar, 1969) reported that some hydrocarbons are exclusively produced by the γ-radiation of lipids and lipid-containing foods, hydrocarbons have been extensively studied as markers to detect the irradiation of foods. Two types of hydrocarbons are predominantly produced by the irradiation of fatty acids: a hydrocarbon that has one carbon less than the parent fatty acid (C_{n-1}) and a hydrocarbon that has two carbons less and an additional double bond at position 1 (C_{n-2}, 1-ene) (Dubravcic and Nawar, 1968; Spiegelberg *et al.,* 1994). The hydrocarbons exclusively detected in irradiated foods have been suggested to be used as markers for identifying post-irradiation of the foods that are fairly high in lipids, such as meats (Hwang, 1999a), eggs (Hwang, 1999b; Hwang *et al.,* 2001), peanuts (Park and Hwang, 1999), soybean (Hwang *et al.,* 2007) and sesame seeds (Choi and Hwang, 1997). Severe heating of peanut oils induced the formation of some hydrocarbons; however, the pattern of hydrocarbon production by the heating was totally different from irradiation (Lesgards *et al.,* 1993).

The main purpose of this investigation was to study the changes in lipid profile fractions; fatty acids, hydrocarbons and sterols of three oil seeds (soybean, peanut and sesame) as a result of gamma irradiation with a range from 0.5 to 7.5 kGy.

2. MATERIAL AND METHODS

2.1. Materials

Soybean seeds (*Glycin Max* L., *Var. Clark*), Peanut seeds (*Arachis Hypogaea* L., *Var. Giza5)* and Sesame seeds (*Sesame indicum* L., *Var. Giza 32*) were obtained from the Food Legumes Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt.

2.2. Irradiation treatments

Irradiation treatments were performed using the Cobalt 60 source from unit Gamma Chamber 4000, at the National Center for Research and Radiation Technology, Naser City, Cairo at a dose rate of 4.166 rad / second.

2.3. Chemical analysis

2.3.1. Lipid Extraction

The seed oil content was determined using the Soxhlet extraction according to the official method (AOAC, 2000). From each cultivar, 50 g of seeds were ground and then extracted with petroleum ether in a Soxhlet apparatus for 6 h. After extraction, the samples were ground again, but more finely, and extracted for 6 h (second extraction). Petroleum ether was evaporated under reduced pressure using a rotavapor. Lipid content was expressed as g 100 g^{-1} of seed fresh weight.

2.3.2. Separation of fatty acids and unsaponifiables from lipid samples

Lipid material was saponified with methanolic KOH (40%, w/v) for 24 h at room temperature according to Ahmed *et al.* (1986). The unsaponifiables were extracted three times with ether. The aqueous layer was acidified with HCl (1:1, v/v) and the liberated fatty acids were extracted three times with ether. The combined extracts of unsaponifiables and fatty acids were washed several times with distilled water and then dried over anhydrous sodium sulfate.

2.3.3. Methylation of lipid materials

The standard and the sample fatty acids were converted to methyl esters using the ethereal solution of diazomethane according to Vogal (1975).

2.3.4. Determination of fatty acid composition by GC-MS

The fatty acid methyl esters were determined by GC-MS using a Trace GC Model 2000 series produced by Thermo equipped with a Selective Detector Mass Spectroscopy Model SSQ 7000 produced by Finnigan. This equipment was interfaced via HP chemstation version A 02.12 software (Hewelwett-Packard. Avondale, PA). The gas chromatography was equipped with a DB-23 (J & W 122-2362) 25μ capillary column, 60 m x 0.25 mm ID, 0.15 μm. The operating conditions for gas chromatography were as follows: injector temperature 250°C, carrier gas: helium at 30 cm sec^{-1}, measured at 150°C, oven temperature 50°C for 4 min, 150°C for 4 min and held at 250°C until the chromatogram was completed. The detector temperature was 280°C. Mass spectroscopy operating parameters were electron ionization at 70 ev, accelerating voltage 10 kV and scan M/Z range from 50 to 500. (National Institute of Standards and Technology (NIST) library according to Jiang *et al.* (2006)).

2.3.5. Determination of unsaponifiable profile by GC-MS

The unsaponifiable fractions were collected in ether and taken to dryness under vacuum. The residue was analyzed using the gas chromatograph HP 5890 (Hewlett Packard) equipped with the MS detector (MSD 5970), EI, 70 ev and fitted with a capillary column DB-1701 (12 m x 0.18 mm x 0.4 mm; J&W Scientific). The column temperature was programmed from 260 to 300°C while the injection temperature was set at 280°C. Helium was the carrier gas at a flow rate of 0.7 cm^3 min^{-1}. The Identification of peaks was based on the retention time of standard substances and MS spectra. Analyses were run in triplicate. Calculations of percent composition of dimethyl hydrocarbons and demethylsterol fractions were based on the peak area.

2.3.6. Iodine value

The iodine value of the oil extracted from the seeds was determined according to the method described in AOAC (2000).

2.3.7. Statistical analysis

The results were expressed as the mean ± SD to show variations in a group.

3. RESULTS AND DISCUSSION

3.1. Fatty acid composition of irradiated oil seed

The gamma irradiation of oil seeds could produce chemical changes in different constants, especially lipids, by catalyzing their reaction with molecular oxygen caused autoxidation or by direct oxidation of the unsaturated site of fatty acids with free radicals. Therefore, both effects could be superimposed.

3.1.1. Soybean seeds

The results in Table 1 show the effect of different doses of gamma irradiation on the fatty acid composition of soybean. The data show that the non-irradiated soybean contained C16:0, C18:1, C18:2 and C18:3 which comprised more than 86% of total fatty acids and reduced to about 83% in irradiated samples. The γ-irradiation caused the alteration of the unsaturated and saturated fatty acid composition of soybean which showed an increase in the relative amounts of saturated fatty acids; C14:0, C16:0 and C18:0 and a decrease in the unsaturated fatty acids; C16:1, C18:1,C18:2 and C18:3. The ratio between total unsaturated fatty acids and saturated ones (TU/TS) was 3.60 for the control soybean oil seed, while it decreased gradually in parallel with the irradiation doses and confirmed with the results of iodine values (Table 1). The present findings agree with previous studies, where it was found that γ-irradiation had some effects on the physical

Table 1
Fatty acid composition of soybean irradiated with different doses of gamma rays

Fatty Acids	Irradiation dose (kGy)						
	Control 0.0	0.5	1	2	3	5	7.5
Caprilic (8:0)	0.54 ± 0.02	0.79 ± 0.01	0.36 ± 0.01	0.67 ± 0.01	0.75 ± 0.01	0.72 ± 0.010	0.90 ± 0.02
Myristic (14:0)	2.10 ± 0.12	2.34 ± 0.15	2.44 ± 0.06	2.60 ± 0.08	3.09 ± 0.10	3.55 ± 0.08	3.29 ± 0.11
Palmitic (16:0)	11.24 ± 0.21	11.78 ± 0.22	12.16 ± 0.29	12.86 ± 0.14	12.92 ± 0.12	12.97 ± 0.22	13.24 ± 0.13
Stearic (18:0)	2.20 ± 0.09	1.99 ± 0.07	2.00 ± 0.08	1.89 ± 0.07	1.18 ± 0.05	1.86 ± 0.06	1.59 ± 0.07
Oleic (18:1)	5.49 ± 0.16	6.29 ± 0.19	6.91 ± 0.21	6.89 ± 0.22	6.84 ± 0.20	7.05 ± 0.23	7.50 ± 0.22
Linoleic (18:2)	22.18 ± 0.32	22.11 ± 0.34	21.20 ± 0.41	21.08 ± 0.37	21.05 ± 0.31	20.37 ± 0.34	20.30 ± 0.42
Arachidic (20:0)	46.26 ± 0.56	45.56 ± 0.52	45.56 ± 0.64	45.04 ± 0.51	45.00 ± 0.60	44.60 ± 0.63	43.95 ± 0.55
Eicosanoic (20:1)	7.08 ± 0.16	6.50 ± 0.15	6.83 ± 0.14	6.59 ± 0.19	6.41 ± 0.22	6.12 ± 0.13	6.10 ± 0.18
Behenic 22:0	2.51 ± 0.09	2.11 ± 0.11	2.13 ± 0.08	2.13 ± 0.10	2.47 ± 0.13	2.56 ± 0.11	2.45 ± 0.07
Lignoceric (24:0)	0.40 ± 0.06	0.51 ± 0.08	0.41 ± 0.05	0.26 ± 0.02	0.30 ± 0.04	0.21 ± 0.03	0.40 ± 0.07
TS[a]	21.89 ± 0.42	23.32 ± 0.50	24.00 ± 0.51	25.15 ± 0.62	26.06 ± 0.65	26.84 ± 0.70	27.76 ± 0.81
TU[b]	78.11 ± 3.64	76.68 ± 3.3 8	76.00 ± 2.85	74.85 ± 2.51	73.94 ± 2.39	73.16 ± 2.21	72.24 ± 2.09
TU/TS	3.60 ± 0.43	3.29 ± 0.32	3.1 ± 0.30	2.98 ± 0.28	2.84 ± 0.25	2.73 ± 0.22	2.60 ± 0.19
I.V[c]	113.7 ± 0.44	111.3 ± 0.48	111.0 ± 0.37	109.4 ± 0.39	108.4 ± 0.35	107.1 ± 0.29	105.8 ± 0.21

[a] Total saturated fatty acids; [b] total unsaturated fatty acids; [c] iodine value (g $100g^{-1}$). Values are expressed as the means ± SD of three independent assays.

and chemical composition of soybean fatty acids (Basyony *et al.,* 1989; Mahrous, 2007). The autoxidation of the unsaturated fatty acids occurred in soybean oil with fatty acid structure C16:1, C18:1, C18:2 and C18:3 therefore the oxidation depended on the site of the unsaturation. The fatty acid linoleic C18:2 is considered to be the one most affected by γ-radiation which decreased by over 2% followed by oleic C18:1, linolenic C18:3 and palmitoleic C16:1 with an irradiation dose of 7.5 kGy. The data presented in Table 1 illustrate that the iodine value of the crude oil extracted from healthy un-irradiated soybean seeds was 113.7 g $100g^{-1}$, whereas the γ-irradiation with dose levels of 0.5, 1, 2, 3, 5 and 7.5 kGy decreased the iodine value. The iodine value was 105.8 g $100g^{-1}$ at an irradiation dose level of 7.5 kGy as compared with the control. The decrease in iodine value upon irradiation could be attributed to some loss in the un-saturated fatty acids of soybean oil by radiation and the formation of peroxide compounds. These results are in agreement with the results obtained by several investigators (Shahin, 1993, Mohsen, 1996, Mahrous, 2007), who reported that a marked decrease in iodine value was noticed for irradiated soybean, sesame and cotton seed oil and the decrease was proportional to the irradiation doses. The obtained results confirm that irradiation accelerates the autoxidation process in unsaturated fatty acids in the presence of oxygen through the formation of free radicals and causes the breakdown and destruction of the antioxidants and change the chemical constituents of the lipid fraction (Hafez *et al.,* 1985, Nawar, 1978).

3.1.2. Peanut seeds

The same trend for soybean could be observed in the case of the effect of different irradiation doses on the chemical composition of peanut fatty acids as shown in Table (2). The results show a slight decrease in the relative percentages of the unsaturated fatty acids C18:1 and C18:2 and slight increase in the percentages of the saturated ones C14:0, C16:0, C18:0, C20:0 C22:0 and C22:0 with increases in irradiation dosage. The present findings agree with those obtained by Chiou *et al.* (1991). The ratio between total unsaturated fatty acids and saturated ones (TU/TS) was 3.76 for control peanut oil seeds, while it gradually decreased in parallel with the irradiation doses as confirmed by the calculated iodine value. The unsaturated fatty acids of peanut oleic C18:1 and linoleic C18:2 comprised over 88% and affected by γ- radiation and reduced by 3% of the total fatty acid composition. γ- radiation is known to cause the breakdown of the unsaturation site in the unsaturated fatty acid (Chiou *et al.,* 1990). Our results revealed the presence of the short chain fatty acid caprilic C8:0 in irradiated peanut with doses from 0.5 to 7.5 kGy with 0.53 to 0.99% respectively. On the other hand, the long chain saturated fatty acids arachidic C20:0, behenic C22:0 and lignoceric C24:0 were increased to reach their maximum levels with 7.5 kGy. These findings may be due to the inter conversion between fatty acids which occur under the irradiation treatment. The decrease in iodine values of peanut oil ranged from 95.24 to 88.44 g.$100g^{-1}$ oil from the control to 7.5 kGy radiation doses respectively (Table 2). Other investigators also found decreases in the iodine values of gamma irradiated

Table 2
Fatty acid composition of peanut irradiated with different doses of gamma rays

Fatty Acids	Irradiation dose (kGy)						
	Control 0.0	0.5	1	2	3	5	7.5
Caprilic (8:0)	0.34 ± 0.01	0.53 ± 0.02	0.89 ± 0.05	0.89 ± 0.06	0.79 ± 0.04	0.80 ± 0.06	0.99 ± 0.07
Myristic (14:0)	0.40 ± 0.03	0.66 ± 0.05	0.76 ± 0.06	0.82 ± 0.07	0.90 ± 0.08	0.99 ± 0.06	1.08 ± 0.09
Palmitic (16:0)	12.25 ± 0.33	12.49 ± 0.41	13.37 ± 0.49	13.57 ± 0.51	13.70 ± 0.54	13.68 ± 0.57	14.00 ± 0.63
Stearic (18:0)	3.86 ± 0.21	4.40 ± 0.26	4.60 ± 0.29	4.75 ± 0.34	4.83 ± 0.37	4.93 ± 0.40	4.98 ± 0.48
Oleic (18:1)	45.10 ± 0.74	43.30 ± 0.61	42.39 ± 0.59	42.43 ± 0.61	42.12 ± 0.79	41.92 ± 0.67	41.36 ± 0.59
Linoleic (18:2)	31.50 ± 0.55	31.13 ± 0.47	30.23 ± 0.44	30.20 ± 0.59	30.12 ± 0.38	30.06 ± 0.41	29.72 ± 0.29
Arachidic (20:0)	1.74 ± 0.12	2.26 ± 0.14	2.33 ± 0.16	2.18 ± 0.20	2.25 ± 0.18	2.33 ± 0.13	2.34 ± 0.18
Eicosanoic (20:1)	2.40 ± 0.09	2.35 ± 0.11	2.14 ± 0.13	2.02 ± 0.07	1.96 ± 0.05	1.71 ± 0.04	1.78 ± 0.07
Behenic 22:0	1.85 ± 0.11	1.98 ± 0.08	2.35 ± 0.12	2.06 ± 0.10	2.14 ± 0.14	2.36 ± 0.16	2.39 ± 0.18
Lignoceric (24:0)	0.91 ± 0.06	0.91 ± 0.04	0.95 ± 0.07	1.06 ± 0.08	1.20 ± 0.11	1.22 ± 0.13	1.35 ± 0.15
TS[a]	21.00 ± 0.33	23.22 ± 0.31	25.25 ± 0.29	25.34 ± 0.40	25.78 ± 0.42	26.31 ± 0.46	27.14 ± 0.49
TU[b]	79.00 ± 2.36	76.78 ± 2.18	74.75 ± 2.28	74.66 ± 2.43	74.20 ± 2.25	73.69 ± 2.49	72.86 ± 2.37
TU/TS	3.76 ± 0.32	3.30 ± 0.39	2.96 ± 0.24	2.95 ± 0.29	2.88 ± 0.26	2.80 ± 0.31	2.68 ± 0.30
I.V[c]	95.24 ± 0.63	93.01 ± 0.45	90.50 ± 0.49	90.40 ± 0.53	89.93 ± 0.48	89.49 ± 0.51	88.44 ± 0.41

[a] Total saturated fatty acids; [b] total unsaturated fatty acids; [c] iodine value (g 100g^{-1}). Values are expressed as the means ± SD of three independent assays.

oil seeds (Lutfullah *et al.,* 2003, Mahrous, 2007). The oxidation of the unsaturated site of fatty acids after irradiation will have an effect on oxidative conditions, especially antioxidant activity (Camargo *et al*., 2011; Afify *et al.,* 2012b) and change the stability and the quality of oil as proven (Lalas *et al.,* 2007, Mexis and Kontominas, 2009). Gamma radiation (8.0 kGy) increased the primary and secondary oxidation products of peanuts (Bhatti *et al.,* 2010). Furthermore, the concentrations of the secondary grew faster. Volatile secondary compounds such as aldehydes, ketones and alcohols have had their concentration increased in peanuts, pistachio and cashew nuts submitted to gamma radiation with doses up to 7.0 kGy [11,36], which indicate an increase in lipid oxidation (Camargo *et al*., 2011). Therefore the irradiation dose used for the peanut treatment should be selected very carefully without having any side effects on the chemical composition and physical characteristics of the peanut oil seeds (Bhatti *et al.,* 2010).

3.1.3. Sesame seeds

The fatty acid profiles of total lipids of non-irradiated and irradiated sesame seeds at different doses are shown in Table 3. All sesame seed lipids had oleic (C18:1ω-9) and linoleic (C18:2ω-6) acid

Table 3
Fatty acid composition of sesame irradiated with different doses of gamma rays

Fatty Acids	Irradiation dose (kGy)						
	Control 0.0	0.5	1	2	3	5	7.5
Palmitic (16:0)	9.93 ± 0.54	10.58 ± 0.61	10.87 ± 0.68	11.05 ± 0.72	11.37 ± 0.78	11.43 ± 0.70	11.56 ± 0.68
Stearic (18:0)	4.83 ± 0.28	5.45 ± 0.37	5.99 ± 0.36	6.60 ± 0.39	6.97 ± 0.40	7.30 ± 0.41	7.59 ± 0.43
Oleic (18:1)	44.57 ± 0.59	43.93 ± 0.53	43.97 ± 0.47	43.81 ± 0.54	43.16 ± 0.38	42.76 ± 0.69	42.44 ± 0.66
Linoleic (18:2)	40.66 ± 0.55	40.07 ± 0.41	39.17 ± 0.49	38.54 ± 0.44	38.51 ± 0.52	38.51 ± 0.43	38.41 ± 0.47
TS[a]	14.77 ± 0.33	16.00 ± 0.44	16.86 ± 0.35	17.65 ± 0.53	18.34 ± 0.65	18.73 ± 0.66	19.15 ± 0.59
TU[b]	85.23 ± 1.02	84.00 ± 1.08	83.14 ± 0.78	82.35 ± 0.83	81.66 ± 0.94	81.27 ± 0.89	80.85 ± 0.96
TU/TS	5.77 ± 0.52	5.25 ± 0.48	4.93 ± 0.44	4.66 ± 0.39	4.45 ± 0.35	4.33 ± 0.30	4.22 ± 0.29
I.V[c]	108.77 ± 0.87	107.18 ± 0.91	105.65 ± 0.78	104.43 ± 0.93	103.81 ± 0.84	103.48 ± 0.76	103.03 ± 0.81

[a] Total saturated fatty acids; [b] total unsaturated fatty acids; [c] iodine value (g 100g^{-1}). Values are expressed as the means ± SD of three independent assays.

as the most predominant among the unsaturated fatty acids, as well as palmitic (C16:0) and stearic (C18:0) acid as the most predominant among the saturated ones (Zoumpoulakis *et al.,* 2012). The presented data show that an increase in the percentage of the saturated fatty acids C16:0 and C18:0 with a total increase of over 4% and decrease in the percentage of the unsaturated fatty acids C18:1 and C18:2 with a total decrease of over 5% with an irradiation dose of 7.5 kGy. These changes were noticed in the oil extracted from irradiated sesame seeds in comparison with the control sesame oil. The ratio between total unsaturated fatty acids and saturated ones (TU/TS) was 5.77 for untreated oil, while it decreased gradually in parallel with the irradiation doses with iodine values ranging from 108 (control) to 103 (irradiated sesame at 7.5 KGy). The major changes in fatty acid composition were shown in the quantity of unsaturated fatty acids (18:1 and 18:2) which comprise over 85% in the control compared to more than 80% in the irradiated sesame with 7.5 kGy. Irradiation caused a significant gradual decrease in the unsaturated fatty acid content and a significant saturated fatty acid content increase as irradiation dose increased in sesame seeds (Zoumpoulakis *et al.,* 2012). Also, a gradual decrease in iodine values was noticed in irradiated seeds and reached its maximum decrease at the highest dose of 7.5 kGy 103.03 $g.100g^{-1}$ as compared with the control. Although the irradiation dose used in our investigation is permitted to control insects and shelf life of oil seed with doses ranging from 1 to 5 kGy in several countries including Egypt as reported by IAEA (1995) and FAOSTATE (1998). The application of these doses tn food causes a breakdown and disintegration of lipids, especially fatty acids in the site of the unsaturation such as oleic acid C18:1, linolenic acid C18:2 or linolenic C18:3 and produces different types of hydrocarbons which are considered artifacts in the oil seeds. Gamma irradiation with different levels of water deficit (moderate and severe water deficit) decreases the fatty acid content and unsaturation as verified by a significant reduction in oleic, linoleic, and linolenic acid proportions and the disappearance of palmitoleic acid (Yalcin *et al.,* 2011) as revealed in our study. Therefore the next step in our investigation will be to study the new hydrocarbon produced from γ-radiation in the three oil seeds.

3.2. Unsaponifiable matter composition

It is well known that unsaponifiable matter contains several types of substances such as hydrocarbons besides sterols, pigments and vitamins and its very susceptible to being affected by γ-radiation because of its composition, especially the unsaturation sites. The hydrocarbons and sterols of the three oil seeds soybean, peanut and sesame, after irradiation with γ-ray doses of 0.5, 1.0, 2.0, 3.0, 5.0 and 7.5 kGy were studied and demonstrated. Tocopherol could not be detected under these conditions.

3.2.1. Soybean seeds

The data in Table 4 shows the unsaponifiable matter composition of irradiated soybean seeds according to the gamma ray doses. The presented data show that the non-irradiated soybean seeds contain 19:0, 20:0, 21:0, 22:0, 23:0 and 26:0 hydrocarbons which comprise 63% of the total unsaponifiable matter and represents 9.2, 5.2, 19.1, 10.4, 8.7 and 7.6% respectively. The percentages of 22:0, 20:0 and 19:0 were decreased with irradiation depending on the dose. Some new unsaturated hydrocarbons 16:1, 16:2, 17:1 and 18:1 were detected in irradiated seeds with different doses and could not be detected in the control seeds. These results are in agreement with Hwang *et al.* (2007) who found that the hydrocarbons 17:1, 16:2, 17:2 and 16:3, induced from oleic and linoleic acids, were not detected in the lipids extracted from non-irradiated soybeans, while they were detected in fairly large amounts in the lipids from the samples irradiated at every level of tested doses. The detection levels of the hydrocarbons increased with dose. The hydrocarbons 15:0, 16:0 and 14:1, possibly radiation-induced from palmitic acid, and n-hexadecane (16:0) and 1-hexadecene (16:1), possibly from stearic acid, were detected in the non-irradiated samples and increased with irradiated dose. Sterols are quite important substances for human beings as they are the precursor of certain hormones, therefore the levels of sterol or sterol derived compound as affected by γ-radiation effect human health and play a major role in arteriosclerosis. The results in Table 4 show that the non-irradiated soybean seeds contained cholesterol, campesterol, stigmasterol and β-sitosterol and represents 1.2, 6.2, 0.3 and 2.3% respectively with total sterol of 10.2%. The present investigation proves that γ-irradiation affected the sterol content of soybean seeds which decreased by increasing the γ-irradiation dose. Among the total sterols, stigmasterol was considered the major sterol to disappear starting with 3 kGy irradiation doses. The ratio of total hydrocarbons to total sterols (TH/TSt) in irradiated soybean seeds were increased and reached its maximum with 7.5 kGy and represents 36.3 compared to the control 8.8. These results prove that the γ-irradiation of soybean seeds followed a general trend including increasing hydrocarbons and decreasing the sterol compounds. The prominent γ-radiation of soybean induced the unsaturated hydrocarbons 16:1, 16:2, 17:1 and 18:1 which could be derived from the decarboxylation and oxidation of stearic, oleic and may be from linolenic or eicosanoic acids, respectively. In addition to the induced unsaturated hydrocarbons, saturated hydrocarbons were increased by γ-irradiation and include 17:0 and

Table 4
Unsaponifiable matter of soybean irradiated with different doses of gamma rays

Components	Irradiation dose (kGy)						
	Control 0.0	0.5	1	2	3	5	7.5
14:0	3.81 ± 0.23	2.24 ± 0.18	2.53 ± 0.21	2.07 ± 0.19	0.87 ± 0.13	0.13 ± 0.01	0.24 ± 0.02
15:0	0.62 ± 0.04	0.11 ± 0.01	2.99 ± 0.31	4.09 ± 0.37	1.13 ± 0.27	0.19 ± 0.03	0.18 ± 0.01
16:0	0.18 ± 0.02	0.22 ± 0.01	0.46 ± 0.02	0.24 ± 0.01	0.85 ± 0.15	0.98 ± 0.19	0.46 ± 0.06
16:1	0.0	0.46 ± 0.03	0.51 ± 0.02	0.74 ± 0.11	0.39 ± 0.10	0.97 ± 0.21	1.18 ± 0.23
16:2	0.0	0.22 ± 0.02	0.69 ± 0.08	0.72 ± 0.12	1.14 ± 0.11	1.70 ± 0.16	1.80 ± 0.24
17:0	0.32 ± 0.04	1.21 ± 0.14	2.06 ± 0.25	1.27 ± 0.09	0.33 ± 0.05	0.43 ± 0.06	0.36 ± 0.02
17:1	0.0	0.80 ± 0.10	0.84 ± 0.11	0.86 ± 0.12	1.23 ± 0.08	1.57 ± 0.26	2.15 ± 0.30
18:0	0.75 ± 0.04	0.86 ± 0.13	3.33 ± 0.22	5.28 ± 0.34	5.27 ± 0.38	5.39 ± 0.31	2.96 ± 0.13
18:1	0.0	0.0	0.0	0.0	0.26 ± 0.02	0.47 ± 0.04	0.53 ± 0.03
19:0	8.16 ± 0.39	8.96 ± 0.43	7.74 ± 0.44	7.08 ± 0.31	5.35 ± 0.23	4.50 ± 0.21	6.81 ± 0.20
20:0	10.24 ± 0.51	10.89 ± 0.58	9.38 ± 0.25	8.05 ± 0.28	5.13 ± 0.21	9.58 ± 0.41	4.60 ± 0.19
21:0	6.23 ± 0.37	8.25 ± 0.32	7.09 ± 0.40	6.23 ± 0.35	5.10 ± 0.24	1.69 ± 0.11	0.87 ± 0.13
22:0	20.2 ± 0.63	18.5 ± 0.54	20.6 ± 0.59	20.9 ± 0.61	20.4 ± 0.72	20.4 ± 0.56	19.4 ± 0.57
23:0	10.43 ± 0.29	11.27 ± 0.31	5.32 ± 0.22	4.44 ± 0.19	4.33 ± 0.20	3.75 ± 0.18	3.98 ± 0.19
24:0	2.70 ± 0.08	3.15 ± 0.12	3.47 ± 0.15	4.79 ± 0.19	5.67 ± 0.14	6.44 ± 0.17	8.11 ± 0.27
25:0	3.77 ± 0.15	4.33 ± 0.18	5.76 ± 0.21	7.17 ± 0.24	9.50 ± 0.39	10.15 ± 0.33	11.63 ± 0.34
26:0	8.66 ± 0.44	9.47 ± 0.41	10.43 ± 0.48	9.39 ± 0.35	9.30 ± 0.39	8.84 ± 0.49	9.59 ± 0.29
27:0	2.19 ± 0.11	3.05 ± 0.14	4.11 ± 0.18	6.69 ± 0.25	9.79 ± 0.27	10.11 ± 0.31	11.70 ± 0.43
28:0	2.40 ± 0.23	2.93 ± 0.17	3.41 ± 0.21	4.71 ± 0.29	6.16 ± 0.22	7.72 ± 0.30	8.97 ± 0.20
29:0	1.51 ± 0.03	1.78 ± 0.05	1.68 ± 0.08	0.13 ± 0.01	1.71 ± 0.14	1.25 ± 0.15	0.11 ± 0.01
Squalene	3.14 ± 0.10	0.24 ± 0.04	0.17 ± 0.02	0.12 ± 0.01	1.05 ± 0.02	0.32 ± 0.03	0.33 ± 0.02
30:0	4.27 ± 0.24	5.17 ± 0.29	2.90 ± 0.13	0.78 ± 0.17	1.18 ± 0.11	0.36 ± 0.04	0.69 ± 0.08
C_{32}	0.22 ± 0.01	0.40 ± 0.03	0.65 ± 0.15	1.47 ± 0.19	0.37 ± 0.07	0.24 ± 0.01	0.72 ± 0.18
Cholesterol	1.234 ± 0.14	1.22 ± 0.12	0.50 ± 0.03	0.29 ± 0.02	0.92 ± 0.04	0.99 ± 0.11	0.92 ± 0.10
Campesterol	6.22 ± 0.43	2.31 ± 0.37	1.48 ± 0.19	1.26 ± 0.12	0.63 ± 0.08	0.48 ± 0.02	0.42 ± 0.01
Stigmasterol	0.36 ± 0.02	0.20 ± 0.01	0.17 ± 0.01	0.15 ± 0.01	0.0	0.0	0.0
β-sitosterol	2.40 ± 0.08	1.80 ± 0.07	1.70 ± 0.10	1.53 ± 0.13	1.37 ± 0.11	1.41 ± 0.09	1.34 ± 0.12
[a]TH	89.79 ± 0.55	94.47 ± 0.64	96.14 ± 0.72	96.77 ± 0.78	97.08 ± 0.62	97.12 ± 0.71	97.32 ± 0.83
[b]TSt	10.21 ± 0.25	5.53 ± 0.14	3.86 ± 0.16	3.23 ± 0.18	2.92 ± 0.21	2.88 ± 0.09	2.68 ± 0.13
TH/TS	8.8 ± 0.28	17.1 ± 0.23	26.2 ± 0.31	29.9 ± 0.36	33.3 ± 0.41	33.8 ± 0.48	36.3 ± 0.52

[a] Total hydrocarbons; [b] total sterols. Values are expressed as the means ± SD of three independent assays.

18:0 which could be derived from stearic and oleic, respectively, as shown in Tables 4 and 5.

3.2.2. Peanut seeds

The present results in Table 6 show the unsaponifiable matter composition of irradiated peanut seeds with major hydrocarbons of 20:0, 22:0, 24:0, 26:0, 28:0 and 29:0 hydrocarbons, which represents 75.5% of the total unsaponifiable matter (Park and Hwang, 1999). The relative percentage of these hydrocarbons represents 11.3, 25.2, 10.6, 12.3, 8.8 and 7.1% respectively. No unsaturated hydrocarbons were detected in the oil extracted from non-irradiated peanuts but saturated hydrocarbons only were detected as shown in Table 5 (Park and Hwang, 1999). On the other hand, the induced unsaturated hydrocarbons; 16:1, 16:2, 17:1, 16:3, 17:2 and 18:1 could be detected only in the irradiated peanut seeds starting from the low level of irradiation dose of 0.5 kGy to the maximum irradiation dose of 7.5 kGy as shown in Table 7.

The relative percentages of the induced unsaturated hydrocarbons were dose dependent and as a general trend, were increased by increasing irradiation dose.

Table 5
Hydrocarbons induced in irradiated soybean seeds

Parent fatty acid	Hydrocarbons %	Irradiation dose (kGy)					
		0.5	1.0	2.0	3.0	5.0	7.5
Stearic acid	$C_{16:1}$	0.46 ± 0.03	0.51 ± 0.02	0.74 ± 0.11	0.39 ± 0.10	0.97 ± 0.21	1.18 ± 0.23
Oleic acid	$C_{16:2}$	0.22 ± 0.02	0.69 ± 0.08	0.72 ± 0.12	1.14 ± 0.11	1.70 ± 0.16	1.80 ± 0.24
	$C_{17:1}$	0.80 ± 0.10	0.84 ± 0.11	0.86 ± 0.12	1.23 ± 0.08	1.57 ± 0.26	2.15 ± 0.30
Linoleic acid or Eicosanoic acid	$C_{18:1}$	0.00	0.00	0.00	0.26 ± 0.02	0.47 ± 0.04	0.53 ± 0.03

Values are expressed as the means ± SD of three independent assays.

Table 6
Unsaponifiable matter of peanut irradiated with different doses of Gamma rays

Components	Irradiation dose (kGy)						
	Control 0.0	0.5	1	2	3	5	7.5
14:0	0.09 ± 0.01	0.08 ± 0.01	0.02 ± 0.01	0.12 ± 0.02	0.61 ± 0.05	0.35 ± 0.03	0.98 ± 0.06
15:0	0.14 ± 0.02	0.32 ± 0.04	0.53 ± 0.08	0.71 ± 0.05	1.40 ± 0.12	0.25 ± 0.02	0.21 ± 0.01
16:0	0.26 ± 0.03	0.32 ± 0.02	1.27 ± 0.07	0.15 ± 0.01	1.88 ± 0.05	1.85 ± 0.06	1.86 ± 0.08
16:1	0.0	0.15 ± 0.02	0.33 ± 0.03	0.51 ± 0.04	0.77 ± 0.07	0.80 ± 0.05	1.04 ± 0.10
16:2	0.0	0.13 ± 0.01	0.35 ± 0.02	0.40 ± 0.03	0.43 ± 0.05	0.49 ± 0.06	0.53 ± 0.04
16:3	0.0	0.22 ± 0.02	0.75 ± 0.04	0.79 ± 0.06	0.81 ± 0.07	0.92 ± 0.05	0.95 ± 0.11
17:0	0.0	2.02 ± 0.12	2.03 ± 0.14	2.21 ± 0.11	2.22 ± 0.19	2.13 ± 0.17	2.31 ± 0.15
17:1	0.0	0.37 ± 0.13	0.40 ± 0.16	0.55 ± 0.18	0.96 ± 0.12	1.95 ± 0.22	2.59 ± 0.24
17:2	0.0	0.16 ± 0.02	0.20 ± 0.01	0.26 ± 0.02	0.29 ± 0.03	0.44 ± 0.03	0.72 ± 0.05
18:0	0.30 ± 0.02	0.75 ± 0.06	0.22 ± 0.02	0.12 ± 0.01	2.92 ± 0.04	4.96 ± 0.17	6.02 ± 0.19
18:1	0.0	0.0	0.14 ± 0.01	0.26 ± 0.02	0.70 ± 0.03	0.81 ± 0.04	1.06 ± 0.02
19:0	2.56 ± 0.14	0.98 ± 0.04	1.43 ± 0.08	0.40 ± 0.03	0.50 ± 0.04	0.66 ± 0.07	1.43 ± 0.10
20:0	11.39 ± 0.29	10.89 ± 0.15	9.74 ± 0.13	8.04 ± 0.19	7.26 ± 0.22	5.78 ± 0.16	5.58 ± 0.24
21:0	2.07 ± 0.11	0.96 ± 0.15	1.26 ± 0.18	0.42 ± 0.07	1.36 ± 0.13	3.98 ± 0.11	4.57 ± 0.19
22:0	25.2 ± 0.57	21.6 ± 0.66	20.6 ± 0.71	19.9 ± 0.62	18.9 ± 0.55	14.3 ± 0.48	12.6 ± 0.32
23:0	0.0	0.0	0.0	0.0	0.0	5.39 ± 0.28	6.16 ± 0.21
24:0	10.7 ± 0.26	13.9 ± 0.19	16.7 ± 0.25	18.8 ± 0.18	20.8 ± 0.33	17.6 ± 0.23	15.0 ± 0.17
25:0	5.36 ± 0.18	6.35 ± 0.21	6.76 ± 0.34	6.24 ± 0.38	6.14 ± 0.29	5.72 ± 0.40	5.62 ± 0.41
26:0	12.40 ± 0.45	8.73 ± 0.36	8.38 ± 0.49	8.55 ± 0.27	7.65 ± 0.43	7.82 ± 0.34	7.53 ± 0.31
27:0	6.71 ± 0.26	7.80 ± 0.20	7.86 ± 0.29	10.6 ± 0.31	10.2 ± 0.32	9.24 ± 0.23	8.96 ± 0.46
28:0	8.81 ± 0.19	8.66 ± 0.21	8.24 ± 0.26	7.03 ± 0.34	5.13 ± 0.25	5.12 ± 0.18	5.39 ± 0.22
29:0	7.17 ± 0.12	8.46 ± 0.19	3.39 ± 0.17	6.60 ± 0.27	5.20 ± 0.20	3.67 ± 0.18	2.42 ± 0.11
Squalene	3.05 ± 0.13	3.74 ± 0.26	3.53 ± 0.30	3.42 ± 0.33	2.13 ± 0.16	4.19 ± 0.23	4.28 ± 0.28
30:0	0.66 ± 0.04	1.22 ± 0.11	1.80 ± 0.14	2.29 ± 0.18	0.0	0.0	0.0
32:0	0.37 ± 0.03	0.24 ± 0.01	0.17 ± 0.1	0.26 ± 0.02	0.20 ± 0.01	0.30 ± 0.03	0.66 ± 0.12
Cholesterol	0.15 ± 0.02	0.0	0.0	0.0	0.0	0.0	0.0
Campesterol	0.49 ± 0.03	0.35 ± 0.05	0.31 ± 0.03	0.18 ± 0.02	0.19 ± 0.01	0.13 ± 0.02	0.09 ± 0.01
Stigmasterol	0.31 ± 0.01	0.15 ± 0.01	0.15 ± 0.02	0.15 ± 0.01	0.16 ± 0.02	0.19 ± 0.03	0.09 ± 0.02
β-sitosterol	1.84 ± 0.14	1.47 ± 0.11	1.22 ± 0.14	0.95 ± 0.21	0.92 ± 0.11	0.80 ± 0.14	0.78 ± 0.12
[a]TH	97.21 ± 0.72	98.03 ± 0.88	98.33 ± 0.81	98.72 ± 0.77	98.74 ± 0.89	98.88 ± 0.63	99.04 ± 0.76
[b]TSt	2.79 ± 0.15	1.97 ± 0.21	1.67 ± 0.13	1.28 ± 0.19	1.26 ± 0.14	1.12 ± 0.05	0.96 ± 0.02
TH/TS	34.8 ± 0.29	49.7 ± 0.42	60.0 ± 0.47	77.1 ± 0.55	78.2 ± 0.60	88.2 ± 0.59	103.5 ± 0.92

[a] Total hydrocarbons; [b] total sterols. Values are expressed as the means ± SD of three independent assays.

Table 7
Hydrocarbons induced in irradiated peanut seeds

Parent fatty acid	Hydrocarbons %	Irradiation dose (kGy)					
		0.5	1.0	2.0	3.0	5.0	7.5
Stearic acid	$C_{16:1}$	0.15 ± 0.02	0.33 ± 0.03	0.51 ± 0.04	0.77 ± 0.07	0.80 ± 0.05	1.04 ± 0.10
Oleic acid	$C_{16:2}$	0.13 ± 0.01	0.35 ± 0.02	0.40 ± 0.03	0.43 ± 0.05	0.49 ± 0.06	0.53 ± 0.04
	$C_{17:1}$	0.37 ± 0.13	0.40 ± 0.16	0.55 ± 0.18	0.96 ± 0.12	1.95 ± 0.22	2.59 ± 0.24
Linoleic acid or	$C_{16:3}$	0.22 ± 0.02	0.75 ± 0.04	0.79 ± 0.06	0.81 ± 0.07	0.92 ± 0.05	0.95 ± 0.11
Eicosanoic acid	$C_{17:2}$	0.16 ± 0.02	0.20 ± 0.01	0.26 ± 0.02	0.29 ± 0.03	0.44 ± 0.03	0.72 ± 0.05
	$C_{18:1}$	0.0	0.14 ± 0.01	0.26 ± 0.02	0.70 ± 0.03	0.81 ± 0.04	1.06 ± 0.02

Values are expressed as the means ± SD of three independent assays.

Besides the induced unsaturated hydrocarbon, the saturated hydrocarbon with 17:0 could be detected in irradiated peanut seeds at a high percentage starting from the low level of irradiation dose of 0.5 kGy and represents over 2% which could be used as a biomarker for the irradiated peanuts (Park and Hwang, 1999). It is important to note that the saturated hydrocarbon in the irradiated peanut seeds has no general trend, while 20:0, C22:0, 26:0, 28:0 and 29:0 were decreased; other hydrocarbons 18:0, 24:0, 27:0 were increased depending on the irradiation dose applied. Our results are in agreement with Ming Li *et al.,* (2011) who stated that the hydrocarbons 1,7-C16:2 and 8-C17:1 did not exist in the unirradiated peanuts while they were apparently detected in the sample irradiated at the dose range of 0.5-8.0 kGy. Radiation dose had a significant impact on radiolysis products. A greater radiation dose results in a greater concentration of hydrocarbons. According to Nawar's research, 1,7-C16:2 and 8-C17:1 were produced by oleic acid (C18:1) in the carbonylation of α-C–C and β-C–C bonds of the decomposition products, respectively. In addition, oleic acid in peanuts had a high level (42.42%) of the total oil (Cui *et al.,* 1997), which could be the reason for the relatively high concentrations of 1,7-C16:2 and 8-C17:1 in irradiated peanuts. In the range 0.5–8 kGy, 1,7-C16:2 and 8-C17:1 had a good linear relationship with the radiation dose. The radiation dose can be determined by the concentration of the hydrocarbons, according to this linear relationship and under certain conditions (Ming Li *et al.,* 2011).

3.2.3. Sesame seeds

The data in Table 8 show the unsaponifiable matter composition of treated sesame seeds according to the gamma ray doses. The non-irradiated sesame seeds contained; 17:0, 20:0, 21:0, 23:0, 24:0 and 25:0 which comprise more than 44% of the total unsaponifiable matter, with relative percentages of 4.4, 10.4, 6.08, 14.1, 5.3 and 4.2% respectively. The relative percentage of the hydrocarbons 17:0 and 20:0 were fluctuated according to the irradiation dose applied.

On other hand, the hydrocarbon 22:0 was increased in its percentage as a general trend to reach its induced maximum with 2 a kGy irradiation dose. The hydrocarbons C16:1, 16:2, 16:3, 17:1 and 18:1 could be detected in irradiated sesame depending on the dose as shown in Table 9. The non-irradiated sesame seeds contained sterol compounds; campesterol, stigmasterol and β-sitosterol with relative percentages of 14.9, 4.4 and 26.1%, respectively (Table 8). Our results are in agreement with Choi and Hwang (1997) who reported that no unsaturated hydrocarbons were detected in the oil extracted from un-irradiated sesame seeds. It has been reported that hydrocarbons 16:1, 16:2, 16:3, 17:1 and 17:2 were detected in un-irradiated oils from peanut, sunflower and extra-virgin olive oils and small amounts of 17 alkane and alkenes were naturally present in avocado-pear oil, which made quantitative analysis difficult. The major irradiation-induced unsaturated hydrocarbons 16:1, 16:2, 16:3, 17:1 were detected in the irradiated sesame at 1.0 kGy or higher. The amount of these induced hydrocarbons increased almost linearly with irradiation dose. The percentage of total sterol (45.5% control) was decreased gradually with the irradiation doses of γ-irradiation (9.3% at 7.5 kGy). The γ irradiation doses caused the disintegration of the sterol compounds which could be arranged as follows campesterol < β-sitosterol < stigmasterol. The results show that there are induced unsaturated hydrocarbons and degradation of the sterol compounds as a result of γ-irradiation. The induced hydrocarbons could be predicted from the effect of γ-irradiation on the major constituents of the fatty acids of sesame; oleic 18:1 and linoleic 18:2 which comprise 44.5 and 40.6% and may be from sterol compounds at 45.5%. The detection of unsaturated hydrocarbon in irradiated sesame was previously proven (Choi and Hwang, 1997; Kamal-Eldin *et al.,* 1992).

In conclusion, γ-irradiation caused alteration of the unsaturated and saturated fatty acid compositions of soybean, peanut, and sesame seeds, which showed an increase in the relative amounts of saturated fatty acids and a decrease

Table 8
Unsaponifiable matter of sesame irradiated with different doses of gamma rays

Components	Irradiation dose (kGy)						
	Control 0.0	0.5	1	2	3	5	7.5
16:0	0.22 ± 0.02	0.35 ± 0.03	0.48 ± 0.05	0.15 ± 0.02	0.14 ± 0.02	2.03 ± 0.09	0.32 ± 0.04
16:1	0.0	0.05 ± 0.01	0.06 ± 0.01	0.16 ± 0.03	0.18 ± 0.03	1.30 ± 0.04	1.75 ± 0.11
16:2	0.0	0.13 ± 0.02	0.13 ± 0.02	0.14 ± 0.01	0.15 ± 0.01	0.23 ± 0.03	0.24 ± 0.02
16:3	0.0	0.0	0.0	0.0	0.0	0.85 ± 0.11	0.87 ± 0.14
17:0	4.49 ± 0.18	4.58 ± 0.13	5.38 ± 0.24	5.39 ± 0.28	5.18 ± 0.29	7.07 ± 0.35	1.30 ± 0.19
17:1	0.0	0.35 ± 0.02	0.55 ± 0.06	0.81 ± 0.09	1.08 ± 0.12	2.08 ± 0.28	2.60 ± 0.35
18:0	1.72 ± 0.24	2.37 ± 0.31	3.68 ± 0.41	3.68 ± 0.39	3.71 ± 0.42	3.99 ± 0.38	4.96 ± 0.44
18:1	0.0	0.0	0.48 ± 0.08	0.61 ± 0.11	0.85 ± 0.18	0.93 ± 0.17	1.32 ± 0.20
19:0	0.56 ± 0.03	0.81 ± 0.07	3.78 ± 0.21	3.68 ± 0.18	4.04 ± 0.24	0.61 ± 0.05	0.96 ± 0.10
20:0	10.4 ± 0.19	11.8 ± 0.31	9.81 ± 0.38	13.1 ± 0.42	10.28 ± 0.34	10.08 ± 0.29	11.85 ± 0.48
21:0	6.09 ± 0.17	4.00 ± 0.09	4.48 ± 0.22	5.00 ± 0.25	5.77 ± 0.29	5.50 ± 0.31	6.68 ± 0.34
22:0	1.57 ± 0.04	7.21 ± 0.43	9.30 ± 0.49	11.9 ± 0.50	11.2 ± 0.48	10.2 ± 0.37	9.8 ± 0.35
23:0	14.2 ± 0.43	12.2 ± 0.49	10.4 ± 0.36	10.2 ± 0.28	10.1 ± 0.33	11.8 ± 0.44	12.0 ± 0.57
24:0	5.32 ± 0.24	6.50 ± 0.37	5.26 ± 0.39	6.79 ± 0.42	8.16 ± 0.49	9.26 ± 0.23	10.2 ± 0.26
25:0	4.29 ± 0.36	5.85 ± 0.41	7.24 ± 0.25	8.21 ± 0.28	8.37 ± 0.29	7.48 ± 0.38	8.11 ± 0.40
26:0	0.39 ± 0.03	6.81 ± 0.19	4.67 ± 0.21	4.89 ± 0.26	5.07 ± 0.34	6.19 ± 0.41	6.77 ± 0.51
27:0	0.15 ± 0.44	5.81 ± 0.48	3.88 ± 0.25	3.33 ± 0.18	2.96 ± 0.17	3.50 ± 0.27	5.47 ± 0.33
28:0	0.40 ± 0.06	3.1 ± 0.14	1.28 ± 0.11	2.40 ± 0.15	2.20 ± 0.23	3.22 ± 0.26	4.35 ± 0.34
29:0	2.91 ± 0.18	1.68 ± 0.11	0.15 ± 0.02	1.23 ± 0.07	2.61 ± 0.11	2.01 ± 0.14	0.71 ± 0.09
Squalene	0.57 ± 0.04	0.48 ± 0.03	0.27 ± 0.03	0.08 ± 0.01	0.90 ± 0.05	0.09 ± 0.01	0.05 ± 0.01
30:0	0.30 ± 0.02	1.1 ± 0.09	0.10 ± 0.01	0.31 ± 0.02	0.89 ± 0.08	0.0	0.0
32:0	0.93 ± 0.10	0.76 ± 0.12	0.37 ± 0.04	0.30 ± 0.03	0.59 ± 0.04	0.12 ± 0.02	0.18 ± 0.03
Campesterol	15.0 ± 0.49	9.62 ± 0.43	6.38 ± 0.27	5.11 ± 0.25	4.92 ± 0.26	3.59 ± 0.29	2.55 ± 0.18
Stigmasterol	4.40 ± 0.28	4.13 ± 0.22	6.52 ± 0.31	1.31 ± 0.10	2.15 ± 0.28	1.97 ± 0.10	1.47 ± 0.15
β-sitosterol	26.13 ± 0.52	10.6 ± 0.30	10.0 ± 0.17	9.32 ± 0.46	7.97 ± 0.33	6.05 ± 0.29	5.42 ± 0.34
[a]TH	54.48 ± 0.78	75.6 ± 0.89	77.1 ± 0.91	82.3 ± 0.92	84.9 ± 0.90	88.4 ± 0.88	90.6 ± 0.98
[b]TSt	45.52 ± 0.65	24.4 ± 0.51	22.9 ± 0.32	17.7 ± 0.41	15.1 ± 0.45	11.6 ± 0.49	9.44 ± 0.53
TH/TS	1.19 ± 0.11	3.1 ± 0.34	3.36 ± 0.26	4.63 ± 0.44	5.63 ± 0.39	7.60 ± 0.23	9.59 ± 0.45

[a] Total hydrocarbons; [b] total sterols. Values are expressed as the means ± SD of three independent assays.

Table 9
Hydrocarbons induced in irradiated sesame seeds

Parent fatty acid	Hydrocarbons %	Irradiation dose (kGy)					
		0.5	1.0	2.0	3.0	5.0	7.5
Stearic acid	$C_{16:1}$	0.05 ± 0.01	0.06 ± 0.01	0.16 ± 0.03	0.18 ± 0.03	1.30 ± 0.04	1.75 ± 0.11
Oleic acid	$C_{16:2}$	0.13 ± 0.02	0.13 ± 0.02	0.14 ± 0.01	0.15 ± 0.01	0.23 ± 0.03	0.24 ± 0.02
	$C_{17:1}$	0.35 ± 0.02	0.55 ± 0.06	0.81 ± 0.09	1.08 ± 0.12	2.08 ± 0.28	2.60 ± 0.35
Linoleic acid or	$C_{16:3}$	0.0	0.0	0.0	0.0	0.85 ± 0.11	0.87 ± 0.14
Eicosanoic acid	$C_{18:1}$	0.0	0.48 ± 0.08	0.61 ± 0.11	0.85 ± 0.18	0.93 ± 0.17	1.32 ± 0.20

Values are expressed as the means ± SD of three independent assays.

in the unsaturated fatty acids. The ratio between total unsaturated fatty acids and saturated ones (TU/TS) decreased gradually in parallel with the irradiation doses and confirmed with the results of iodine values. The iodine values decreased in the three oil seeds and the decrease was proportional to the irradiation doses. The detection of the induced saturated and unsaturated hydrocarbons was made only in the irradiated oil seeds. The relative percentages of the induced unsaturated hydrocarbons were dose dependent and as a general trend, increased by increasing the irradiation dose. The detection of the induced saturated and unsaturated hydrocarbon could be used as a biomarker index for irradiated food or for biological insect control. The induced hydrocarbons could be predicted from the effect of γ-irradiation on the major constituents of fatty acids or may be derived from the degradation of sterol compounds or from the disintegration of the high molecular weight components of the cell structure in the three oil seeds. Therefore irradiation dose should not exceed the permitted irradiation dose as recommended and lowering the dose should be taken into consideration in order to meet the requirements and lower the side effects resulting from its application to food consumption.

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